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ESSENTIAL PREPARATIONS FOR LANDING ON THE MOON

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The earth's natural satellite, the moon, has been the subject of attention since ancient times. In recent times, people are frequently remarking that the moon will be the first celestial body to be reached by man. The creation of powerful launching rockets, piloted spacecraft, and maneuverable space vehicles in our country is a pledge that a moon flight will take place. However, its beginning will not be the launching of a moon rocket itself, but the preparatory work which still must be done. At the Third International Meeting with Journalists, N. S. Khrushchev stated that Soviet scientists were working on this problem. They are studying it precisely as a scientific problem, and are conducting the essential research.

The first series of moon rockets was launched in the Soviet Union in 1959. The second space rocket which was launched on 12 September 1959 reached the surface of the moon in the vicinity of the crater Autolycus in the Mare Imbrium on 14 September at 00h 02m 24s Moscow time. On 4 October 1959, the third space rocket was launched, enabling an automatic interplanetary station equipped with a complicated set of apparatus to be sent to the moon. On 7 October, the station photographed the far side of the moon, which is unobservable from the earth, and transmitted tracings of its image to ground centers (Figure 1). An analysis of a map of the moon, compiled by Soviet scientists, showed that the side of the moon visible from the earth has more deep depressions, or maria, while the side we cannot see has higher continental regions.

Differences in the heights of such regions in the visible hemisphere of the moon are clearly shown by the arrangement of the contour lines on the hypsometrical map (Figure 2). As can be seen from this figure, the deepest depressions on the terrestrial side of the moon are the Mare Humorum and the Mare Imbrium. Some areas of these two depressions are 5.2 and 6.1 km below the mean level of the moon's surface, while the high regions of the lighter continental part of the hemisphere are 3.5 km above this mean level.

It has now become possible to compile more detailed hypsometrical maps of individual areas on the moon, with contour lines being spaced every 300 m. Studies of this type of map of the visible hemisphere have shown that any maria area should be the most convenient region for landing on the moon.

Flights of automatic space stations and of manned interplanetary spacecraft to the moon and planets of the solar system will be impracticable

unless these vehicles are capable of maneuvering on the flight path and in the vicinity of planets. Landing on a given area of the moon is particularly complicated. Launching the Polet-1 spacecraft was an important step toward designing satellites capable of maneuvering in flight. The pilots of these spacecraft and the crews of long-range expeditions will be able to move at will in space and to select the most suitable landing sites.

Before launching a moon-bound spacecraft, scientists must resolve a number of questions. What is the structure and the composition of the uppermost layer of the moon's crust? What about its microrelief and density? Is the moon's surface covered with dust or a layer of rock fragments (and if this is the case, how deep), or is its surface a rocky, volcanic foam?

These questions must be taken into account when considering landing conditions, especially since the moon has practically no atmosphere.

This lack of atmosphere leads to a situation where the moon's surface may be directly bombarded by meteorites of various sizes, and constantly exposed to corpuscular solar radiation, as well as to other cosmic rays.

Finally, due to the lack of atmosphere, astronauts landing on the moon cannot use parachutes to reduce landing speeds.

Readers of our journal know from an article by V. Sharonov¹ how much information Soviet astronomers have acquired on the structure of the uppermost layer of the moon's crust by observing changes in the brightness of lunar areas. The temperature of the moon's surface has been determined through measurements of infrared radiation. Radio waves emitted by the moon have been established, and the moon has been reached with 10 and 70 cm radar waves.

What do the scientists believe in regard to the structure of the moon's crust? The proponents of the volcanic origin of the moon's relief, who cite the presence of extremely dissected, high mountain ranges and regions having an abundance of crevices (with widths up to tens of kilometers) and overhanging walls, believe that the solid rock has emerged to the lunar surface.

These conclusions are based on comparisons of the mean photometric characteristics of enormous areas (up to several tens of kilometers in diameter) of the lunar surface with characteristics of samples of terrestrial rocks investigated in laboratories.

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Aviatsiya i kosmonavtika, No. 4, 1963.

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Photometric data are very important in determining the nature of the moon's surface. They enable one to conclude that there are no lunar sections with a reflecting power higher than 0.29 or lower than 0.03, the latter being associated with the darkest section of the moon's surface; i.e., the bottom of Tsiolkovskiy Crater (on the far side of the moon) which we measured from photographs obtained from Lunik III. Measurements of the reflecting power of such terrestrial "moon-like" rocks as pumice, granite, basalt, dunite, etc. yielded values from 0.4 to upper limits which considerably exceed the reflection from Tycho Crater, one of the brightest areas on the moon.

As is well known, the hypothesis that the surface of the moon is covered with dust as much as tens of meters thick was advanced by the English scientist Gold as early as 1955. However, even a simple morphological study of the structure of lunar mountain ranges and of those sections of the moon's maria and craters which have an abundance of crevices (for example, the zones of Hyginus and Ariadaeus crevices, and the overhanging fault in Birt Crater) contradicts the existence of deep basins of dust on the moon. Dust cannot remain on almost overhanging walls.

There is a proposition that the lunar pumice (which could have been formed when gases were flowing from the hot magma at the time the crust was hardening) is very porous because the force of gravity on the moon is one-sixth that of the earth. For the same reason, the lunar pumice must be less dense than terrestrial pumice.

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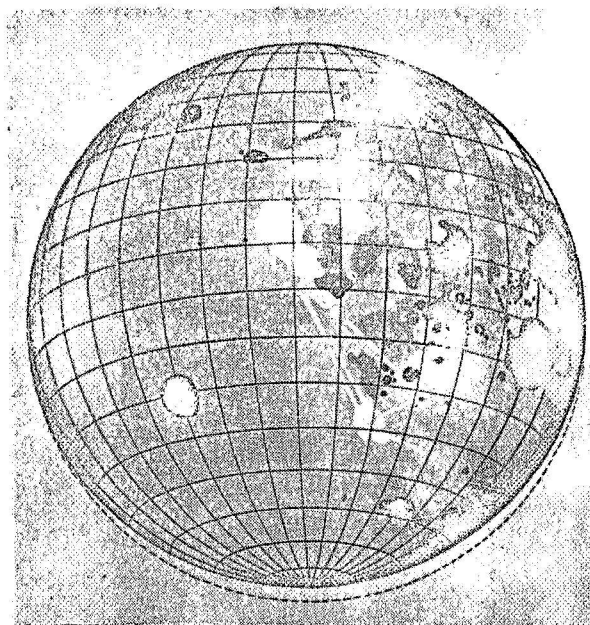


Figure 1. Map of the far side of the moon

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1000 1000
1000 1000

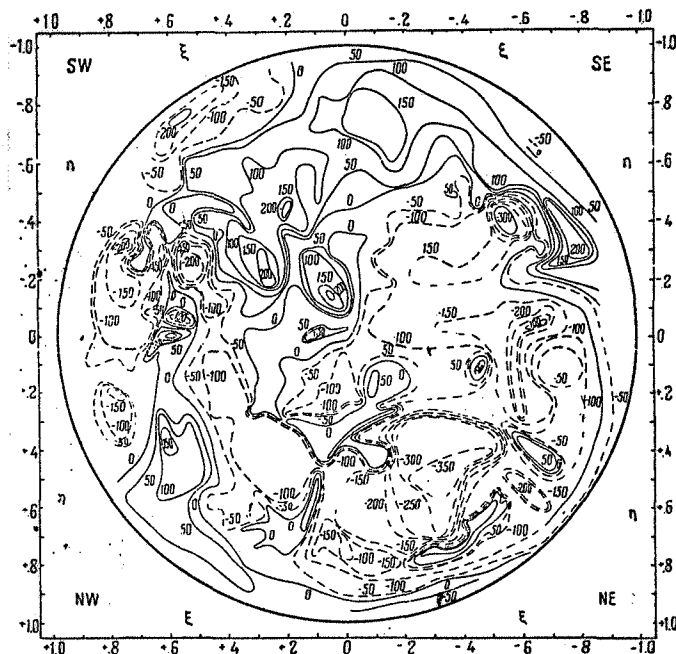


Figure 2. The distribution of horizontal contour lines over the visible hemisphere of the moon. The solid lines are above, while the dashed lines are below the mean level; 100 divisions are equal to 1,734 km

Photometric peculiarities of the reflection of light by the moon's surface (the Barabashev-Markov effect) showed that at least 70 percent of the elements of the moon's surface must be at a very large angle to the horizontal plane, and not more than 30 percent perpendicular to a plumb line. This indicates the extremely dissected nature of the moon's surface.

The low albedo¹ of details of the moon made it possible for students at Leningrad University to propose the meteorite-scoria hypothesis (the hypothesis that meteorites constantly influence the surface of the moon's crust) and to express assumptions on the characteristics of the upper layer to a depth of several millimeters. They used radio-astronomical methods, and conducted a temperature study of the moon so that the sizes of the microirregularities could be made more precise.

The temperature of individual lunar zones having diameters of not less than 50 km was measured with radio transmission equipment.

¹The albedo shows what fraction of incident light is scattered by a given surface.

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Thermoelectric measurements, with wavelengths on the order of 8μ , enabled the physical properties of lunar sections having diameters as small as 6 kilometers to be determined.

Polarization investigations of the moon's surface have also been conducted. Analysis of the results indicated that they are completely dissimilar to the polarization produced by a crust formed by the fusion of meteorites, and by solid rock. However, the curves of changes in polarization with different phases of the moon differ slightly from the curves obtained in the laboratory for powdery materials.

Proceeding on the basis of investigations of terrestrial rocks, including grained powders from minerals and sands ground to various degrees of fineness, one can assume that the uppermost crust of the moon either has a fine-grain structure, or is heavily dissected.

It is interesting to note that an analysis of thermoelectric measurements of the temperature and the heat conductivity of the exposed layer of the moon's crust, and a comparison with measurements of the

heat conductivity of terrestrial powders at a vacuum of 5×10^{-4} ¹ made it possible to conclude that the exposed part of the moon's cover may consist of a layer of grains measuring on the order of a millimeter or of a fraction of a millimeter in diameter down to a depth of 5 centimeters.

Spectroscopic investigations of the light reflected by lunar details provide grounds for more or less reliable conclusions regarding the existence of silicon compounds on the moon. Spectrograms obtained by the Soviet scientists Kozyrev and Yezerkiy on 4 November 1958 indicated that the vapors coming from crevices in the bottom of Alphonsus Crater contain carbon.

Gold believes that the experimental and theoretical investigations conducted in the laboratory of Cornell University in 1963 (with samples of terrestrial rocks that reflect light in a manner similar to the moon) again support the hypothesis that the moon's surface is covered with a shallow layer of fine dust formed from the lunar crust, and that the uppermost layer must have a volumetric density of about one-tenth the density of solid rock in the earth's crust.

Photometric data confirmed both the heavily dissected nature of the outermost layer of the moon's surface and the conclusions on its very low density. Radio measurements of lunar radiation showed that values of the dielectric constant for the deepest layer of the crust varies from 1.6 to 2.7, while it is much larger for terrestrial rocks, i.e., on the

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order of 4 to 45. Consequently, the materials in the depths of the moon's crust must be less dense than that in the earth's crust.

New results from laboratory measurements of samples of terrestrial powders, which were first heated in a vacuum and then crushed, are interesting. The powders were subjected to this treatment so that their behavior inside the moon's crust could be determined, in case they were crushed by an overlying column of dust. The pressure from above was determined while considering the lunar vacuum and values of the force of gravity on the moon. Samples of dunite were crushed into fine particles to a size of 10 microns. It was found that with these dimensions, the adhesive forces between particles was an order of magnitude greater than the weight of the grains themselves, thus illustrating the strength of such a column of particles.

Prior to the experiment, a part of the dunite powder was blackened in an argon atmosphere at a temperature of $+150^{\circ}\text{C}$ to free the surface of water vapor. Then the powder was cooled to room temperature. A 12-mm layer of this dust was subjected to a compression force (in dynes/cm²) which varied during the experiment, as would the force at different depths of the moon's crust.

A similar experiment was conducted with dunite powder which had been in water vapor for 17 hours. For comparison, an analogous experiment was conducted with Portland cement powder (its particles were the same size as those of the dunite powder) which was first dehydrated and then placed in a water-vapor atmosphere for 10 hours. These experiments yielded very interesting results (refer to the table and to Figures 3 and 4).

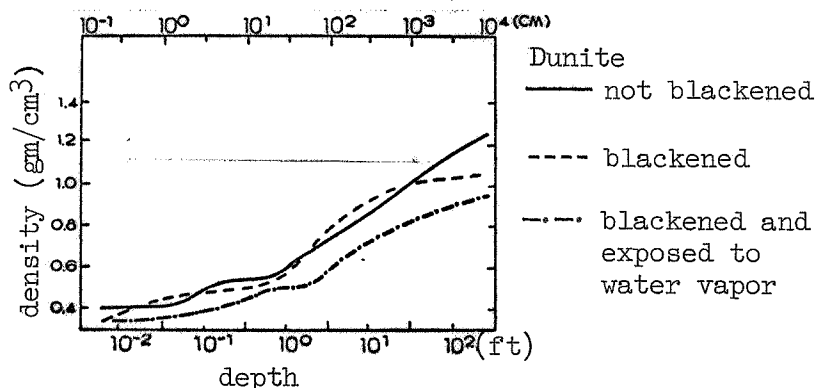


Figure 3. Changes in density in a column of dunite powder with depth (on the moon)

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Depths		Density in the Column of Powders				
cm	m	Dunite			Cement	
		Not black-ened	Black-ened	Moist-ened for 17 hours	Not moist-ened	Moist-ened for 10 hours
0.1	0.001	0.4	0.3	0.3	0.55	0.50
1.0	0.010	0.4	0.44	0.32	0.60	0.55
10.0	0.100	0.52	0.45	0.40	0.80	0.57
100.0	1.000	0.68	0.75	0.50	1.27	0.60
1000.0	10.000	1.04	1.00	0.80	1.47	0.90
10,000.0	100.00	1.2	1.08	0.97	1.56	1.30

At a depth of 10 to 20 cm, the density, which is affected by the pressure exerted by the overlying layer, increased slowly at first and then sharply at about one meter. At depths on the order of 100 m, the density reached only 1.0 for dunite and 1.4 for cement, although they had respective densities of 3.2 and 2.8 before grinding.

It should be noted that under actual conditions, the moon's surface will be subjected to the influence of cosmic rays, which was not the case in the laboratory experiments conducted at Cornell University. However, even with this restriction, after examining the table and Figures 3 and 4, we come to the following conclusions.

If laboratory experiments reproduce the conditions prevailing on the surface of the moon and in the upper layers of its crust closely enough, then the density of the basic rock (dunite), on the order of 0.4 to 0.5, will be maintained in the upper zone to depths not exceeding 30 cm.

Beginning at 30 cm to 1 m, the density of the powder column grows, and at depths on the order of 10 to 100 m it will be scarcely three times greater.

The fact that the density of lunar soil is about 0.5 down to depths of about 30 cm was noted as early as 1960 by Professor V. S. Troitskiy. Foreign scientists advanced proposals on the nature of the increased density in deeper layers.

To obtain more accurate distinctions in the degree of irregularity of lunar formations (i.e., various types of maria, continents, and craters with bright rays), American astronomers used the work of Lenin-grad and Khar'kov Universities and showed that the bottom areas of craters with rays were most heavily dissected, while the continents and maria were less dissected. /51

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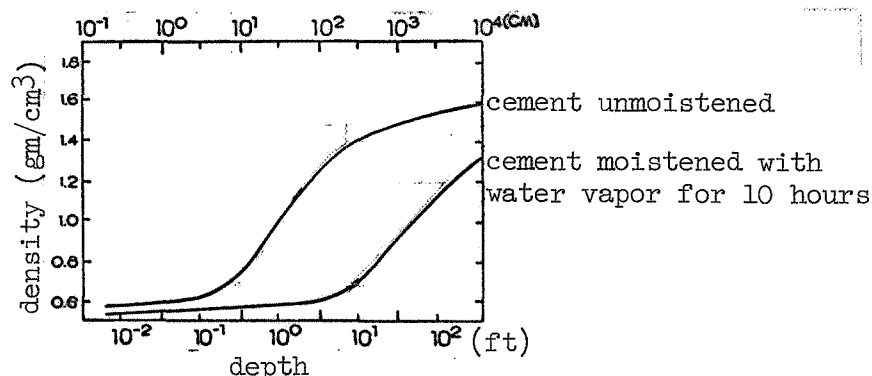


Figure 4. Changes in density in a cement powder column with depth (on the moon)

Although 55 percent of the area of lunar craters are associated with heavily dissected zones, the new calculations indicate that only 35 percent of the area of the remaining objects is dissected. It is interesting to note that the volumetric density of rocks in craters with rays should be not more than 0.34 the density of solid rock, and for the other objects it is 0.45.

If we consider the probable distribution of densities with depth in the bottoms and in sections near the bottoms of craters with rays (like Tycho), the result obtained from processing radar observations of these features is particularly interesting. When scientists succeeded in separating the peculiarities of the reflection of 70-cm radio waves from individual formations on the moon, it was found that the radio waves were reflected from the entire surface of the moon (except for the bottoms and the banks of craters with bright rays), as though they were reflected from a fairly deep layer of dust or porous rock. On the other hand, craters with a light aureole showed an effect in reflecting radar beams which was close to that which should be noted in the reflection of radio waves from solid rocks with density on the order of 2.0 and covered with a layer of white dust.

The fact that the bottoms of craters with rays may actually have such a structure was confirmed by measurements of temperatures during total eclipses of the moon. Although the near surroundings of Tycho Crater were cooled from +120°C to -90°C, Tycho itself was cooled only down to -40°C. During eclipses, its temperature was 50°C higher than those in neighboring sections. This is because there is only a millimeter layer of white powder lying on the rock in the bottom of Tycho Crater which is denser than the rock in its vicinity. This is also confirmed by calculations of cooling conditions when solar radiation is blocked.

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We can also draw some general conclusions in regard to the probable structure of the upper layers of the moon's crust. The hypothesis that the moon's surface is covered with a layer of dust to a depth of tens of meters is not valid. The experiments conducted by Cornell University indicate that beginning with a depth on the order of 0.5 m, the crust has a density close to unity. Dust, or a very porous soil of low density can probably exist on the moon at depths not exceeding 30 to 50 cm.

The craters with rays may be considered the most youthful formations on the moon, and it appears that they are the formations which have solid rock closest to the moon's surface.

It is possible that one of the moon's maria zones in the eastern part of the visible hemisphere will be chosen as the site for the landing of the first spacecraft. Before we set out on the first voyage to the moon, it will be necessary to complete all investigations. It will also be necessary to consider the probability of the low volumetric density of the upper layer of individual zones of the moon's crust, after calculating the landing speed and developing the design of the first spacecraft which will investigate the properties of the lunar soil.

Translated for the National Aeronautics and Space Administration
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